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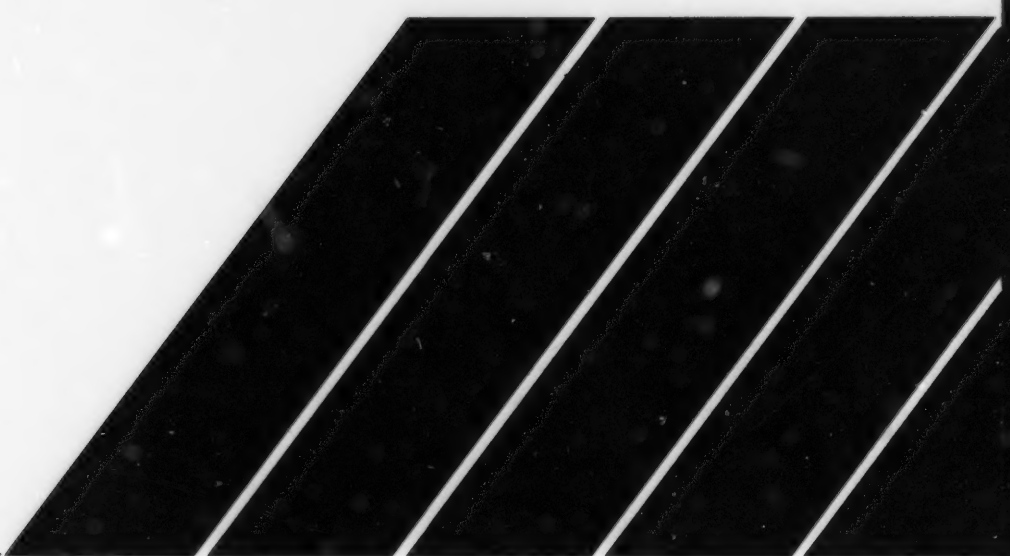
PEAT FAST PYROLYSIS USING THE RTP PROCESS



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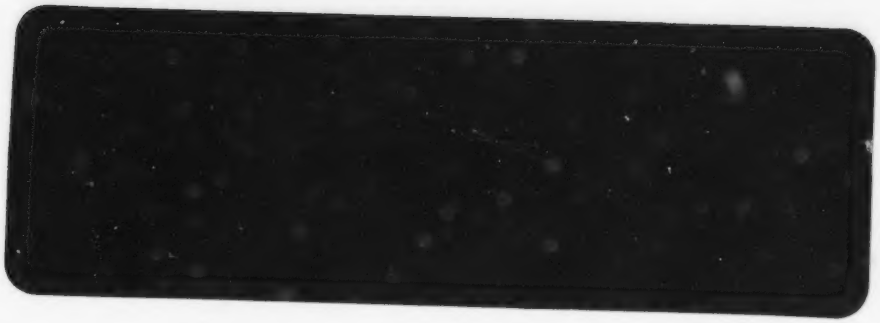

PEAT FAST PYROLYSIS USING THE RTP PROCESS

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PREFACE

This report outlines a preliminary investigation of the fast pyrolysis of peat utilizing Ensyn's Rapid Thermal Processing (RTP) technology. One experiment was performed using a 5 kg/h downflow transport reactor (RTP-I) followed by three tests on a one tpd pilot plant (RTP-III). The experiments were conducted in Ensyn's research facility in Gloucester, Ontario.

Published information on the fast pyrolysis of various peat feedstocks, particularly results from research conducted at the University of Waterloo, has clearly shown that the effective condensation and collection of peat derived liquids requires a different approach from that found to be optimum for wood-derived pyrolysis oils. Despite this information it was agreed that no attempt would be made to redesign or extensively modify Ensyn's existing RTP systems specifically for processing of peat. Funding constraints severely limited the scope of the project, and the primary objective had been established to cover only consideration of the actual transported-bed reactor performance. It was recognized at the outset that efficient liquid product collection would be difficult with the present system configuration.

ABSTRACT

A preliminary investigation of the fast pyrolysis of peat using Ensyn's Rapid Thermal Processing (RTP) approach was conducted with support from the Bioenergy Development Program (BDP) of Energy, Mines and Resources Canada (EMR). A total of four peat pyrolysis experiments were performed; one test in the 5 kg/h RTP-I laboratory scale plant and three in the 1 tpd RTP-III pilot plant. The first experiment was conducted in the smaller unit (515 °C, 200 ms) to determine appropriate procedures for feeding the peat feedstock and to confirm the suitability of selected reaction parameters. Three subsequent experiments were conducted in the RTP-III system, one at 500 °C and two at 600 °C with the residence time maintained at approximately 400 ms.

The relatively fine, dry peat was successfully pyrolyzed in both RTP reactors. No difficulties were encountered with feeding of the peat in the existing wood-feeder system, although the feedrate was significantly reduced as a result of the much lower bulk density of the peat. No problems were encountered with the reactors which achieved reliable steady-state operation.

As expected, difficulties were encountered with collection of the product liquids and therefore, quantitative mass balances were not obtained.

At longer residence times (400 ms) product yields appeared to be comparable to those reported by other researchers (1). Char yields were somewhat lower and estimated total liquid yields higher, when operating at shorter residence times (200 ms).

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RÉSUMÉ

Une étude préliminaire de la pyrolyse rapide de la tourbe au moyen du procédé thermique rapide (PTR) de Ensyn a été menée grâce à l'appui du Programme de développement de la bioénergie (PDB) d'Énergie, Mines et Ressources Canada (ÉMR). Quatre expériences de pyrolyse de tourbe ont été effectuées en tout : une dans le réacteur de laboratoire PTR-I de 5 kg/h et les trois autres dans le réacteur pilote PTR-III de 1 tonne/jour. La première expérience a été conduite dans le petit réacteur (515 °C et 200 ms) afin de déterminer la bonne manière d'alimenter le réacteur en tourbe et de confirmer la validité des paramètres de réaction choisis. Les trois autres expériences ont eu lieu dans le réacteur PTR-III, une à 500 °C et les deux autres à 600 °C; le temps de séjour a été maintenu à environ 400 ms dans les trois cas.

La tourbe sèche, relativement fine, a été pyrolysée avec succès dans les deux réacteurs. L'alimentation en tourbe au moyen de l'actuel système d'alimentation en bois n'a pas posé de difficulté, bien que la vitesse d'alimentation fut considérablement réduite en raison de la densité apparente beaucoup plus faible de la tourbe. Les réacteurs ont fonctionné de façon fiable en régime permanent et aucun problème n'a été éprouvé à cet égard.

Comme prévu, la collecte des liquides a posé des difficultés et il n'a pas été possible en conséquence d'établir des bilans de masse quantitatifs.

Pour de longs temps de séjour (400 ms), le produit donne un rendement en apparence comparable à ceux qu'ont signalés d'autres chercheurs (1). Pour de courts temps de séjour (200 ms), la quantité de charbon produite était un peu moindre et la masse totale estimée des liquides supérieure.

1.0 INTRODUCTION

Rapid Thermal Processing (RTP) is a fast, highly flexible process, capable of selectively converting a variety of carbonaceous feedstocks into high yields of a broad spectrum of products including; liquid and gaseous fuels, petrochemicals, and specialty or bulk chemicals. At the heart of the process is a novel transport reactor system which employs a solid heat transfer medium. This reactor system permits extremely rapid heat transfer to the feedstock, and facilitates short contact times, constant reaction temperatures and rapid product cooling. These features, coupled with the ability to substitute a particulate catalyst for the solid heat carrier, permit effective product selection and yield optimization. The ranges of reactor residence times and temperatures investigated to date are 30 to 1500 ms and 450 to 1000 °C, respectively.

Research and development has been conducted in cooperation with a number of private and public sector clients. Feedstocks which have been investigated include wood, cellulose, lignin, gas oils (vacuum and atmospheric), heavy oil, bitumen, and pitch (refinery residues). Products of interest include fuel additives, liquid fuels, fuel gases, synthesis gas, petrochemicals and specialty chemicals.

ENCON of Calgary, Alberta, has secured considerable private sector interest in the conversion of peat to activated char and liquid fuels via fast pyrolysis. Peat feedstocks have been successfully pyrolyzed at the laboratory scale in a shallow fluidized-bed reactor, in a multi-hearth vacuum pyrolysis reactor and in various ablative reactors, but these techniques have not been implemented on a larger-scale commercial basis. Since Ensyn's RTP pyrolysis process has been

industrially proven for wood in a prototype 2.5 tpd commercial plant, ENCON has expressed interest in examining the potential for using peat feedstocks in the RTP process.

With support from the Bioenergy Development Program of EMR, a preliminary investigation was undertaken which involved the processing of an OCLANSORB peat feedstock in Ensyn's existing RTP pilot plants.

2.0 PROJECT OBJECTIVES

The general objective of this project was to conduct preliminary trial runs on a peat feedstock in the RTP reactor systems to confirm the practical conversion of this material to value-added liquid and solid products. Specific objectives included:

- to secure an adequate supply of a dry particulate peat feedstock;
- to prepare the RTP reactor systems for operation on this feedstock;
- to conduct preliminary fast pyrolysis tests (using both the 5 kg/h and 1 tpd systems) at different reaction conditions;
- to collect primary products (liquid, char) for further analyses;
- to characterize the by-product gas (g.c. analysis).

3.0 FLOW SCHEMES AND EQUIPMENT

3.1 RTP-I

The RTP-I laboratory-scale pilot plant, including its principal components, is illustrated in Figure 1. The plant is rated nominally at 2 - 5 kilograms per hour depending on the specific feedstock characteristics.

Hot solids (i.e., sand or catalyst) flow from a "heat carrier" feeder to the reactor system where they are injected into the rapid thermal mixer. The carbonaceous feed material (solid, liquid, or gaseous) is delivered from one of several interchangeable feeders (i.e., the peat feeder in the present configuration) to the top of the reactor where it is injected into the cloud of turbulent hot solids. Extremely rapid heating of the feed material is achieved as the feed and hot sand particles are quickly and thoroughly mixed. After the fast, intimate mixing is complete, the feed and solid heat carrier pass through a tubular downflow transport reactor, the length of which is selected to control the processing (residence) time.

The vapours are rapidly cooled in a transfer line after the hot solids are cyclonically removed to a solids catch-pot or drop-out vessel. Additional cooling is carried out in the primary (water-cooled) and secondary (dry ice/glycol-cooled) condensers, where condensation of vapours and recovery of liquids also occur. A fibre filter is used to collect persistent aerosols, and the clean gas is then directed through an orifice meter (to measure the flow for mass balance closure). A fraction of the non-condensible product gas is continuously bled from the main stream to a sample bag for subsequent analyses

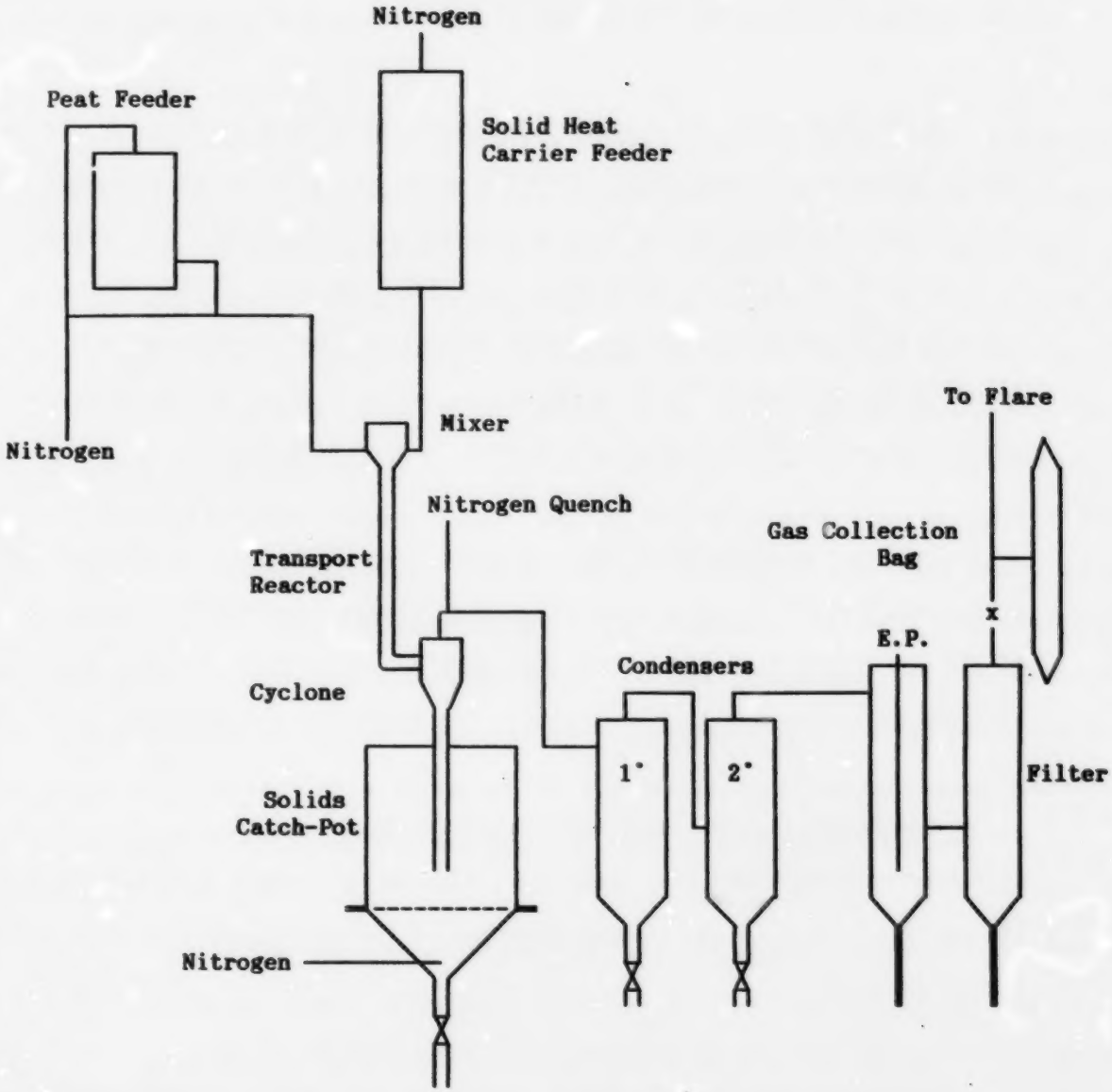

Figure 1. RTP-I Flow Scheme: Rapid Thermal Processing of Peat.

by gas chromatography. When the aerosol loading is particularly high, an electrostatic precipitator is installed between the condensers and the filter.

A variable speed screw is used to meter the biomass from the feeder which has an inventory of about 1 kg. From the screw exit, the solid feedstock falls into a conical chamber where it is picked up and carried into a transport line by a controlled flow of nitrogen. The delivery rate of the feedstock is controlled by adjustment of the speed control of the screw drive motor. The feedrate can be varied from 0 to about 5 kg per hour, and is independent of the transport gas flowrate and the solid heat carrier flowrate.

The reactor system consists of a rapid thermal mixer and a selected length of transport reactor - each with independent temperature control. Rapid mixing of the feedstock with the solid heat carrier takes place in the mixer, and chemical reactions continue through the transport reactor section.

A high-efficiency cyclone separates the gas/vapour stream from the solid heat carrier and product char which are collected in a nitrogen purged catch-pot. The gas/vapour stream is nitrogen quenched at the cyclone exit to stop further reactions.

Both the primary and secondary condensers are stainless steel vessels which sit in liquid baths. Cooling water is used in the primary condenser to achieve a product temperature of about 25 °C. The secondary condenser sits directly in an insulated glycol/dry ice bath. It has a tangential gas/vapour inlet which forces the products to the condenser wall where efficient heat transfer can occur. The outlet temperature is about -10 °C.

To ensure the removal of any entrained condensed liquid or fine solid residue, an electrostatic precipitator and a final filter are utilized.

3.2 RTP-III

The basic flow diagram for the RTP-III plant is illustrated in Figure 2. The peat is batch fed through a lock hopper system to a feed bin which provides a continuous flow of material to the reactor. An auger in the bottom of the feed bin meters the feedstock to the reactor feed screw. The RTP-III system is essentially a four stage reactor configuration: 1) heat carrier heat-up zone; 2) feedstock and heat carrier rapid mixing zone; 3) conversion to products in a transport reactor; and 4) heat carrier separation from the products and recycle to the heat carrier heat-up zone. The feedstock enters the reactor radially just below the mixing zone and is contacted by a stream of hot inert heat carrier (sand or catalyst) and its transport fluid (recirculation gas). The net result is thorough and rapid mixing and conductive heat transfer (including ablation) from the heat carrier to the feedstock. Conversion of the solid feedstock to a raw product vapour is initiated in the mixing zone and continues through a transport reactor section and into the heat carrier separation section.

The solid heat carrier is removed from the product stream and returned to the reactor by a short residence time reverse flow cyclone. A portion of the char produced in the pyrolytic reactions (the larger char particles) is removed with the solid heat carrier at this point, while the smaller char particles are carried with the product vapours to the secondary separator. The secondary separator, a high efficiency reverse flow cyclone, removes the remaining solid material (char, solid heat carrier fines) from the product stream.

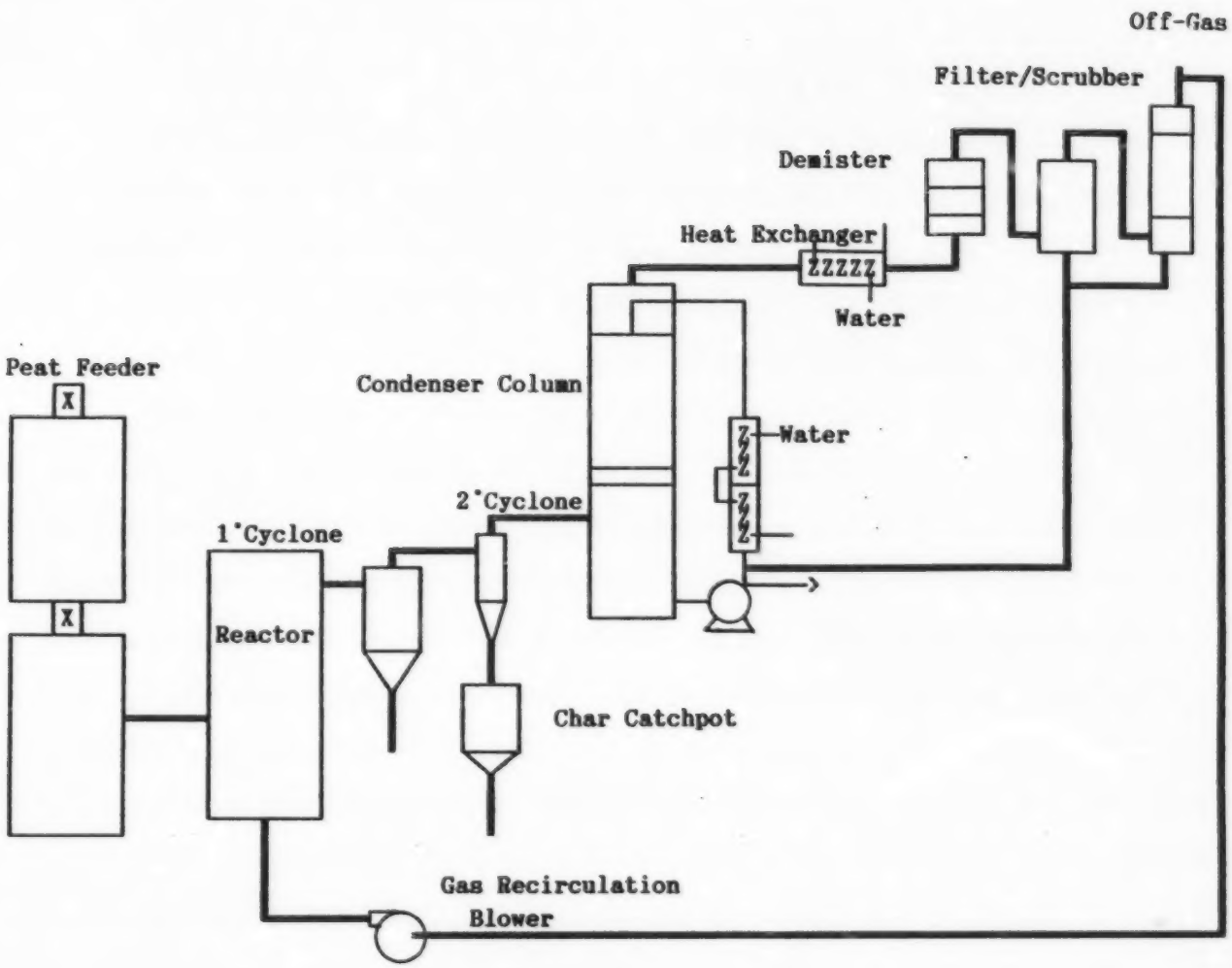

Figure 2. RTP-III Pilot Plant

The hot product stream exiting the secondary separator (condensible and non-condensible product, plus any very fine residual char and ash) is quenched in a packed condenser column and the condensed liquid collected from the bottom of the column. The temperature of the gaseous stream exiting the packed column is reduced further in a water-cooled, glass, heat exchanger.

Any liquids which are carried off from the condenser system (as an aerosol) are removed in a demister and filter. The clean by-product gas is then flared to atmosphere. A portion of the cooled, clean, gas stream is compressed and recirculated to the reactor as the heat carrier and product transport medium.

4.0 SYSTEM PREPARATION

4.1 RTP-I Preparation

A review of published research on the fast pyrolysis of peat indicated that persistent aerosols of heavy tar components could be expected in the vapour stream. To improve collection efficiency the secondary condenser of the RTP-I system (5 kg/h) was fitted with stainless steel demister pads to increase surface area.

Calibration of the feeder was performed with the peat feedstock in order to establish control settings for specified operating regimes. No difficulties were encountered in utilization of the wood feeder system for the peat, although it was necessary to screen out the few long splinters (apparently wood) present in the OCLANSORB. The maximum feedrate for the very low density peat was significantly lower than that for a particulate wood feedstock.

4.2 RTP-III Preparation

In preparation for the peat pyrolysis tests in the RTP-III system, the condensing system was cleaned out (wood had previously been run) and the final product collection filters replaced. The feed system was tested and calibrated using the peat feedstock. Since larger feed screws are used in the RTP-III system no prescreening of the feedstock was necessary. Calibration of the feeder confirmed that less peat could be fed at a given motor control setting relative to wood feeding. As a result, the maximum throughput of peat was about one-half the normal wood feed rate. Larger feed screws would be required to feed at the reactor design capacity.

5.0 FEEDSTOCKS AND SOLID HEAT CARRIER

5.1 Peat Feedstock

Approximately 80 kg of OCLANSORB, a peat absorbent, were purchased locally from A.F. Pollution Abatement Systems Inc. Samples of this feedstock were sent to B.C. Research for characterization, and the following data was obtained.

Table 1. OCLANSORB Peat Characteristics

Moisture Content (as received)	8.13 %
*Ash Content (MF)	0.85 %
Higher Heating Value (MF)	18.50 MJ/kg
Elemental (MAF)	
Carbon	52.00 %
Hydrogen	4.98 %
Nitrogen	0.77 %
Sulphur	1.86 %
Oxygen (diff.)	40.39 %

*This unusually low ash content for a peat product was confirmed by several independent ash determinations conducted by Ensyn.

5.2 Solid Heat Carrier

The solid heat carrier was F-40 grade non-porous silica sand supplied by Indusmin, St. Canut, Quebec. The mean particle diameter is 256 μm, the moisture

content less than 0.5% by mass, and the uncompacted density 1390 kg/m^3. The sand consisted of 99.6% SiO_2.

6.0 RESULTS

6.1 RTP-I Pyrolysis Test

A 37 minute test run was carried out in the RTP-Ia reactor system with a reactor temperature of 515 °C, and a residence time of 200 ms. A total of 317 g of peat were pyrolyzed. A summary of the products produced follows.

6.1.1 Non-Condensible Gas Product

Total gas yield was 11.6% of the as-fed peat, weight basis, with 99.4% of the gaseous product consisting of carbon oxides (CO and CO_2). Specific gas yields were as follows:

Table 2. Summary of Gas Component Yields for the RTP-I Run

	Yield (wt% of feed)	Proportion of Gas (%)
Carbon Dioxide	9.23	79.40
Carbon Monoxide	2.32	20.00
Ethane	0.005	0.04
Ethylene	0.061	0.53
Propylene	0.002	0.02

6.1.2 Char Product

Total char yield, determined by combustion loss tests on solid residues collected from the sand catch-pot and from the recovered liquid products, was 19.8% of the as-fed peat, weight basis.

6.1.3 Liquid Product

An aqueous liquid product was drained from the primary condenser at the conclusion of the test run. This product represented only 6.9% of the as-fed peat, weight basis.

Heavier fractions were deposited throughout the collection system (condensers, electrostatic precipitator, filter). These were measured by weighing the collection system components before and after the run, and recovered by a solvent washing. Recovered organic liquids represented only 44.0% of the as-fed peat, weight basis.

Despite the extra effort taken to increase collector efficiency, it was obvious that condensed aerosols were escaping since the exhaust gases had a visible plume. Assuming complete mass closure and no other losses, this fraction would represent a maximum of 17.7% of the as-fed peat, weight basis.

6.2 RTP-III Runs

Three tests were carried out using the RTP-III pilot plant. A total of 38.5 kg of peat were fed during the tests. The average feed rate, about 10 kg/h, was substantially below the rated plant capacity for wood as a result of feeder

limitation when operating on the very low density peat. The first peat run was conducted at a reactor temperature of 515 °C, and a residence time of 370 ms. The second and third tests were both conducted at 600 °C and a residence time of 430 ms. A summary of the operating conditions for the runs is given in Table 3.

Table 3. Summary of the Experimental Conditions for the RTP-III Runs

RUN	PEAT-1	PEAT-2,3
TEMPERATURE (°C)	515	600
RESIDENCE TIME (ms)	370	430
PEAT FEEDRATE (kg/h)	14.8	13.5
RUN DURATION (min)	30	165

In the first peat run, the system was shut down after 30 minutes due to noticeable pressure increases across the condenser system. The second and third peat pyrolysis tests were carried out using direct contact water circulation in the condensing column. This enabled extended runs with no noticeable pressure increases due to recovery equipment clogging.

Gas samples were taken during the runs and analyzed in a Carle Refinery GC. During the second run the GC was not operational. A third run was conducted, identical to the second, to obtain GC analysis.

Dry char was collected in the catch-pot. Char which had carried over to the condensers was allowed to settle out of the collected liquids which were decanted off. The wet char was collected and dried. A sample of the liquid was

filtered to determine the concentration of suspended solid residue. The total char product was taken as the sum of the dry char, the dried char from the recovery equipment, and the suspended char in the liquid. As a result of condenser limitations it was not possible for all of the liquid to be recovered in a pure form. The total liquid yield was therefore determined by difference (the amount of peat fed minus the amount of char and gas collected). The product yields for Peat-2 and Peat-3 were determined on a combined run basis.

6.3 Results from RTP-III Runs

A summary of the estimated product yields is presented in Table 4.

Table 4. Summary of Estimated Yields

RUN	TEMP (°C)	RES TIME (ms)	ESTIMATED YIELDS (wt% of feed) LIQUID (by diff.)	GAS	CHAR
RTP-1	515	200	68.6	11.6	19.8
RTP-III PEAT-1	515	370	60.3	9.9	29.8*
RTP-III PEAT-2,3	600	430	48.2	29.4	22.4*

* after correction for apparent sand content (loss on combustion)

6.3.1 Non-Condensible Gas Product

The non-condensible gas yield from the RTP-III run at 515 °C (Peat-1) was slightly lower than that for the RTP-I run at the same temperature (9.9% vs 11.6%) but again consisted primarily of carbon oxides (95.4%) with only small amounts of hydrocarbon gases. With the higher reactor temperatures in run Peat-2,3 the yield of non-condensible gases was increased to 29.4%, still mostly carbon oxides but with a yield of just over 2% of hydrocarbon gases. A summary of the gas component yields is presented in Table 5.

Table 5. Summary of Gas Component Yields for the RTP-III Runs

	Yield (% of feed)		Proportion of Gas (%)	
	PEAT-1	PEAT-3	PEAT-1	PEAT-3
Carbon Dioxide	6.91	17.10	69.9	58.20
Carbon Monoxide	2.53	10.30	25.6	35.00
Ethane	0.05	0.20	0.5	0.68
Methane	0.20	0.95	2.0	3.20
Ethylene	0.05	0.40	0.5	1.40
Propylene	0.00	0.20	0.0	0.68
C5/C6	0.09	0.20	0.9	0.68

6.3.2 Char Product

A char sample from RTP-III, run Peat-2,3, was sent to B.C. Research for analysis and the following data was received:

Table 6. Char Analysis from RTP-III Peat-2,3

Moisture Content (as received)	1.72 %
Ash Content (MF)	21.9 %
Higher Heating Value (MF)	19.8 MJ/kg
Elemental (MAF)	
Carbon	95.12%
Hydrogen	3.52%
Nitrogen	1.31%
Sulphur	0.47%
Oxygen (diff.)	0.00%

The analysis of the char sample collected from Peat-2,3 showed a very high ash content (21.9%) indicating an abnormally high carry-over of attritted fines from the heat carrier sand. The weight of collected solid product from the runs was, therefore, corrected to a char only content to provide the values shown in Table 4.

As expected, a higher reactor temperature gave a lower char yield. A comparison of the RTP-I data with that of Peat-1 in the RTP-III system suggests higher char yields with the larger plant.

6.3.3 Liquid Product

Condensed liquids from the Peat-2,3 run were collected from four sections of the condenser system; the primary condenser, the secondary heat exchanger, the demister section and the final filter. Analyses of the first three products gave very little useful data as a result of the very high water contents (from the quench water). The filter, however, collected a relatively pure, waxy solid which had a MC of 31.3% and an ash content of 0.5%.

6.4 Comparison with University of Waterloo Peat Runs

Although a different peat was used for the RTP tests, a general comparison can be made with published data from tests conducted by the University of Waterloo on the fast pyrolysis of peat.

The maximum total liquid yield obtained for the fast pyrolysis of Sogevex peat using the Waterloo fast pyrolysis process was about 56% at a temperature between 500 and 550 °C, with a residence time of about 450 ms. The RTP-III run conducted at 515 °C and 370 ms gave very similar results with an estimated total liquid yield of 60% (vs 56%), a gas yield of 10% (vs 12%), and a char yield of

30% (vs 32%). At 600 °C the RTP-III gas yield was higher (29% vs 23%), the char yield similar (22% vs 24%) and the estimated liquid yield slightly lower (48% vs about 53%).

The RTP-I system, with a very short residence time (at 200 ms vs 370 for RTP-III and 450 ms for Waterloo), apparently gave greater liquid yields with a much lower char output.

7.0 SUMMARY AND CONCLUSIONS

7.1 Summary

A relatively fine, dry peat feedstock was successfully pyrolyzed in Ensyn's RTP reactor systems. No difficulties were encountered with feeding of the peat in the existing wood-feeder systems (although less peat could be fed due to its lower bulk density relative to wood) and no problems were encountered in the reactor systems.

At longer residence times (i.e., greater than 300 ms) product yields were found to be comparable with those reported by other researchers (1). Char yields appeared to be somewhat lower and estimated total liquid yields higher when operating at a residence time of about 200 ms.

7.2 Conclusions

The RTP reactor system can be used successfully to process a dry particulate peat feedstock on a continuous basis for the production of liquids and char. Based on the preliminary runs performed it seems reasonable to conclude that an industrial size RTP unit would provide yields similar to that indicated by tests carried out in the University of Waterloo laboratory-scale pilot plant. In relation to wood processing, a larger-capacity feedstock delivery system would be required and a liquid product collection system designed specifically for the peat oils.

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